CEV OME/RCS Flow Health Monitor: Status Review

Bob Youngquist, Stan Starr

Applied Physics Lab

Steve Simmons, Jeff Carlson

ASRC Aerospace

9/17/08

Overview

- This review provides a progress report and interim results for a project funded by CEV SM (GRC) and by KSC CTC funding.

CEV SM OME/RCS Flow Health Monitor

- Primary purpose: detect propellant valve leakage
  - Reduce launch propellant mass by reducing leakage loss margins,
  - Improve safety by reducing risk of propellant ice build up in thruster
- Secondary objectives:
  - Wetness sensor to detect that lines have been flooded
  - Monitor engine performance (timing, mix ratio)
  - Use in GSE as valve leakage monitor

Preliminary Requirements (from GRC)

- Flow measurement:
  - Low range: 5 ml/hr to 25 ml/hr
  - High range: 23 lbm/s
  - Transient capability (40 ms flow pulse)
  - Reliably indicate sensor wetness
- Media: NTO and MMH (test in water and MMH)
- 4-20 ma current loop output to vehicle data system
- 3/8" OD Ti tubing, 300 psig test pressure

Requirements for Successful Adoption

- To be adopted by the propulsion community, the sensors also must be:
  - Simple,
  - Light in weight,
  - Compatible with hypergols and processes (e.g. cleaning),
  - Not create any additional hazards,
  - Be immune to environmental effects including vibration and temperature gradients,
  - Not require removal and replacement for calibration.

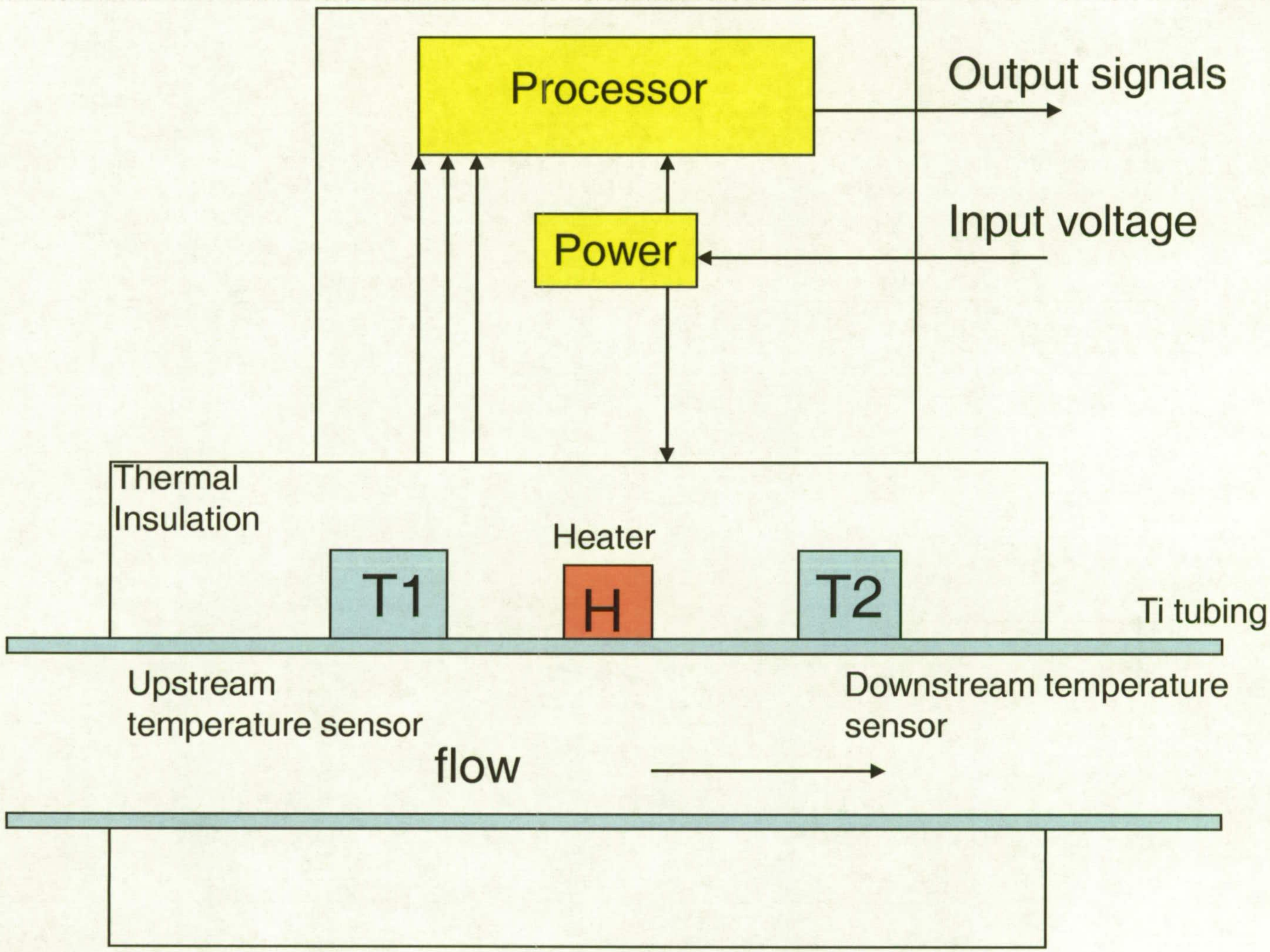
Our Technical Approach

- Flow: Thermal flowmeter, no penetrations, with different configurations for high and low flow:
  - Leakage (Low) Flow (>5 mL/hr reliably): one heater plus two or more temperature sensors
  - High Flow: one heater and co-located temperature sensor. Use closed loop control of heater to maximize turn down ratio (flow measurement range).
- Wetness sensor: pulse heating to measure maximum temperature rise using the low flow configuration.

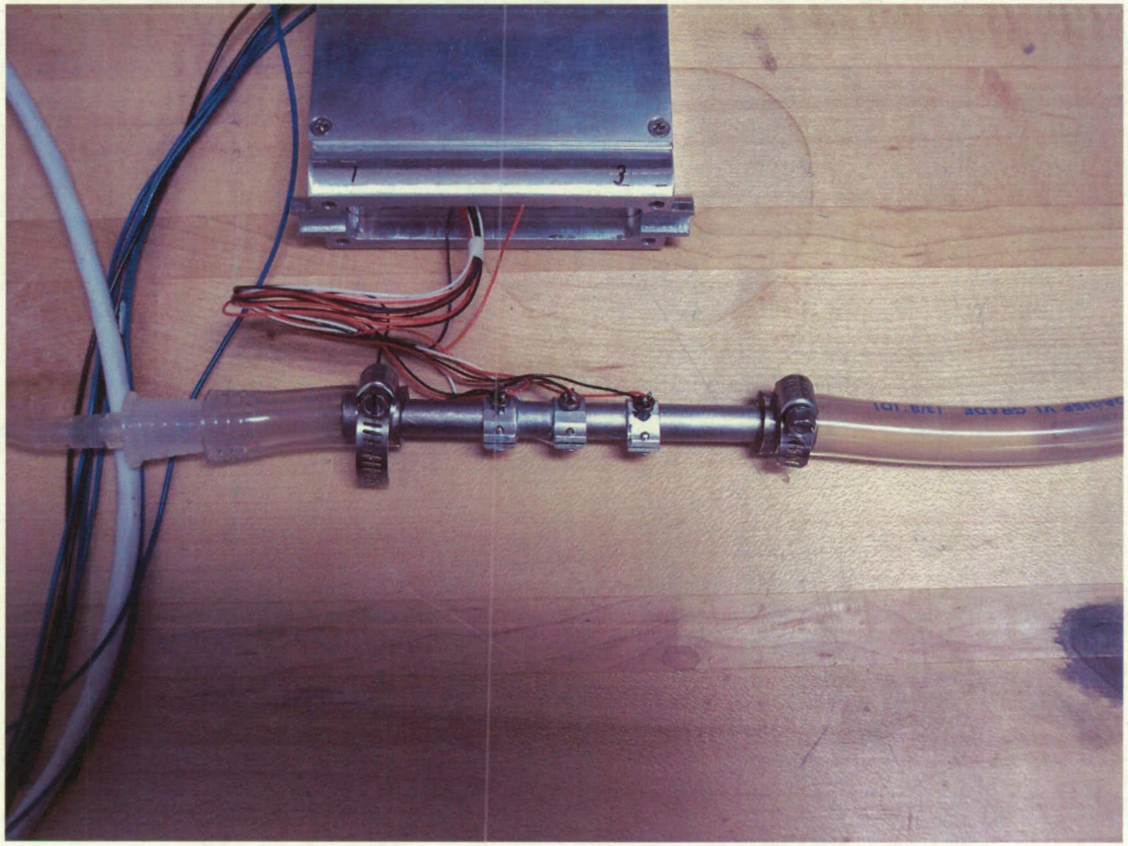
Plan

- First build a prototype low flow meter and test with water.
- Use this same meter in a short pulse mode to test for wetness.
- Use the low flow meter test with both water and MMH in the Applied Chemistry Lab.
- Add features into a 2nd prototype to refine algorithms and performance.
- For high flow, build a very different flow meter with a heater and one temperature sensor.

Low Flow Sensor Conceptual Drawing

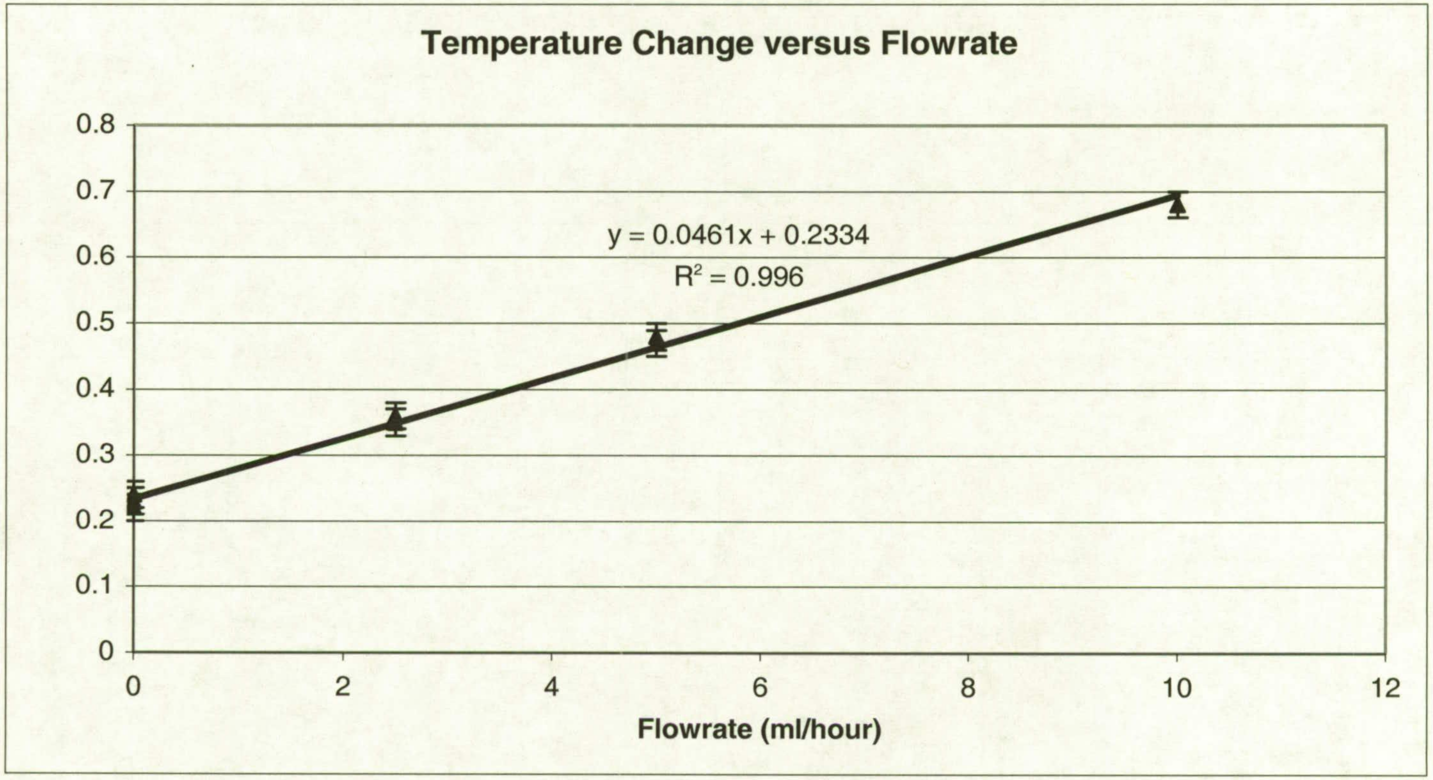


First Prototype



First prototype uses three Aluminum rings (high conductivity) to attach sensors and heater. Machined Al case for electronics. It was later found that the rings were not necessary and we attached sensors directly to the tubing.

Low Flow Performance

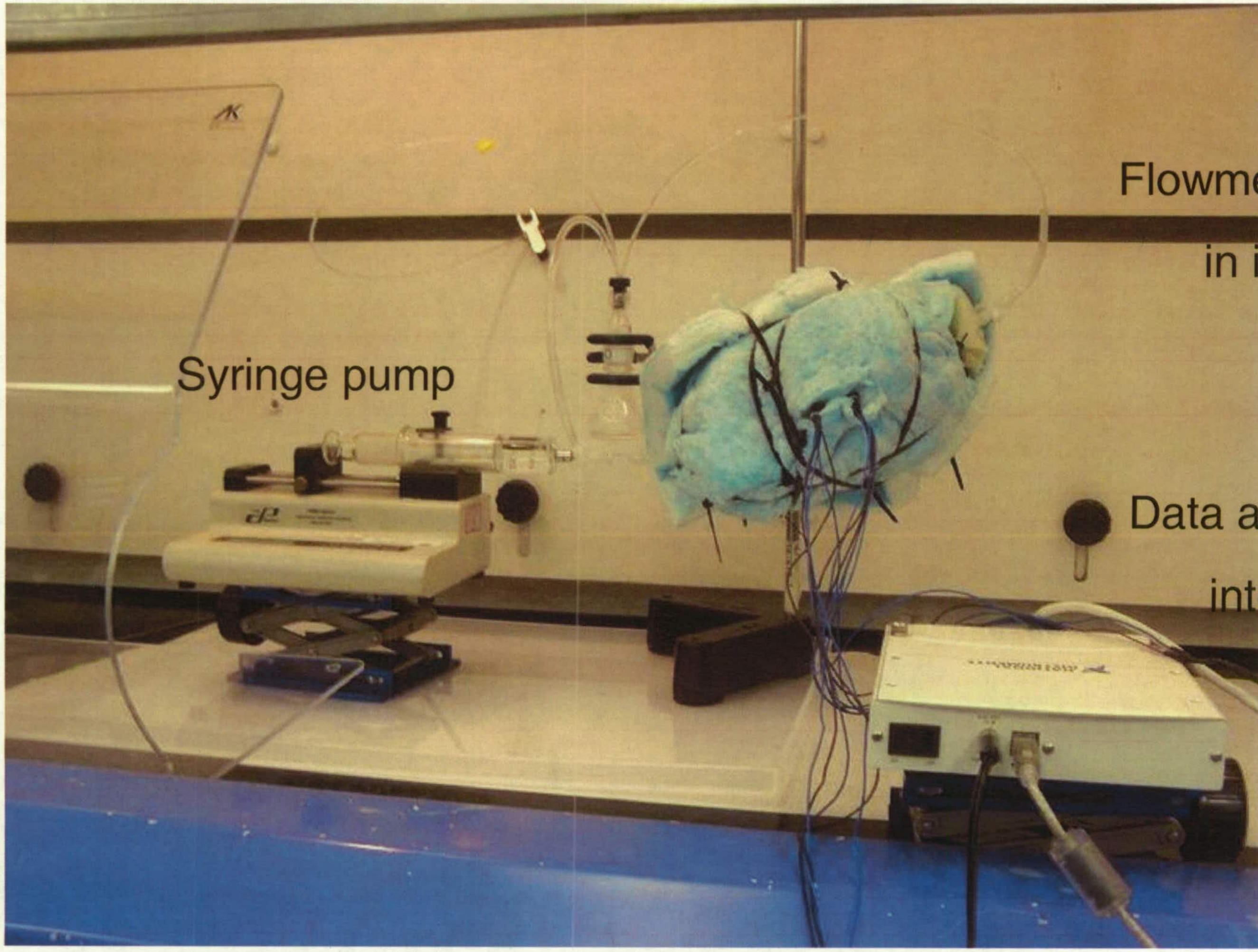


Example flow test (water, low flow) showing reasonable signal levels, repeatability and near linear behavior. Tests are being run at a variety of configurations to explore trade-offs.

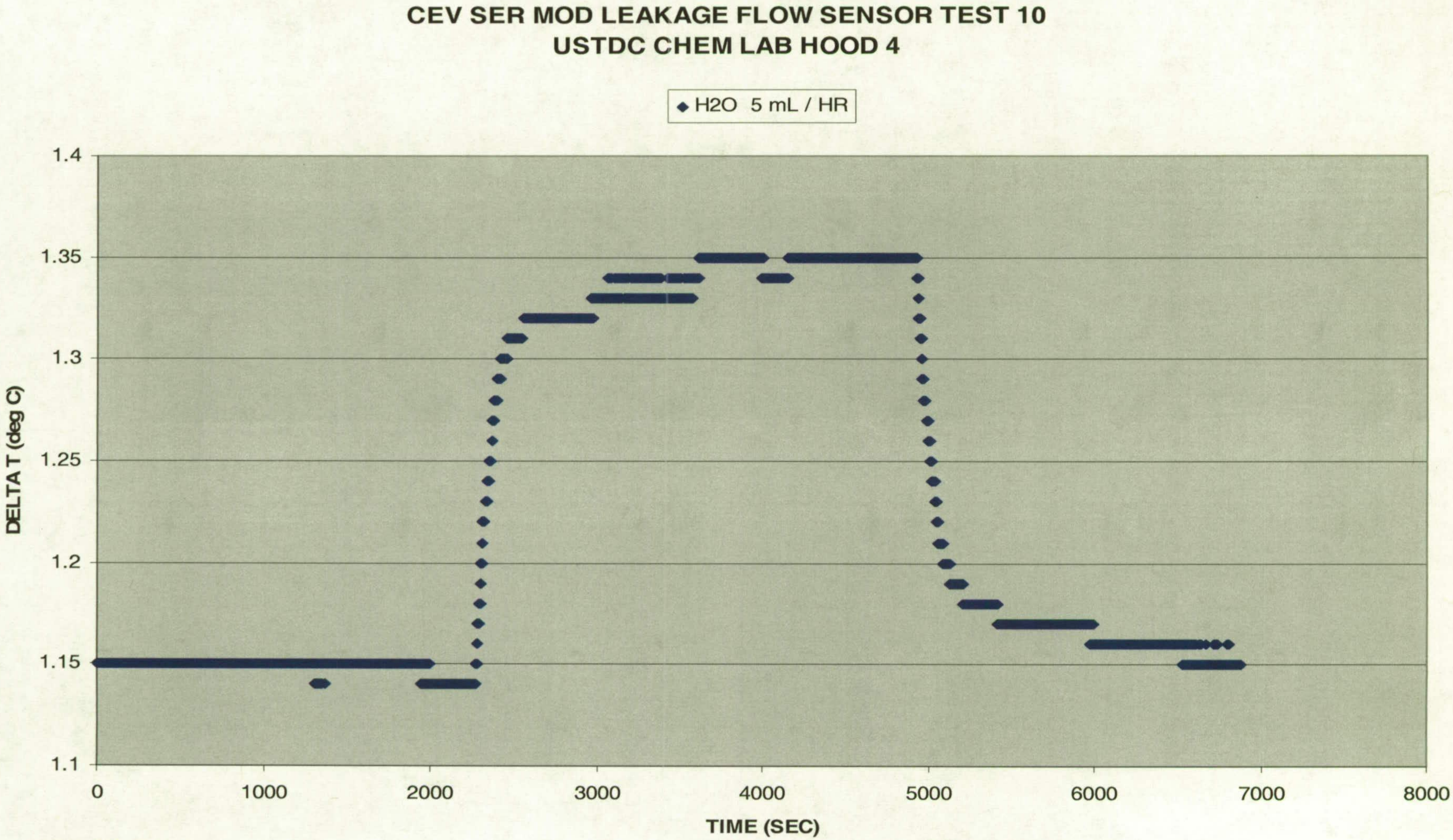
H2O/MMH Testing

- After a student ran a large number of tests with different sensor spacing and insulation configurations, we decided to move the first prototype into MMH flow testing.
- A hazardous procedure was developed, equipment procured and a fume hood configured in the ACL.
- Water flow data appeared fine but reactions between MMH and the ambient air and tubing components corrupted the MMH data (see charts). In addition questions about the safety of the hood caused a re-evaluation of the hood and the procedures.

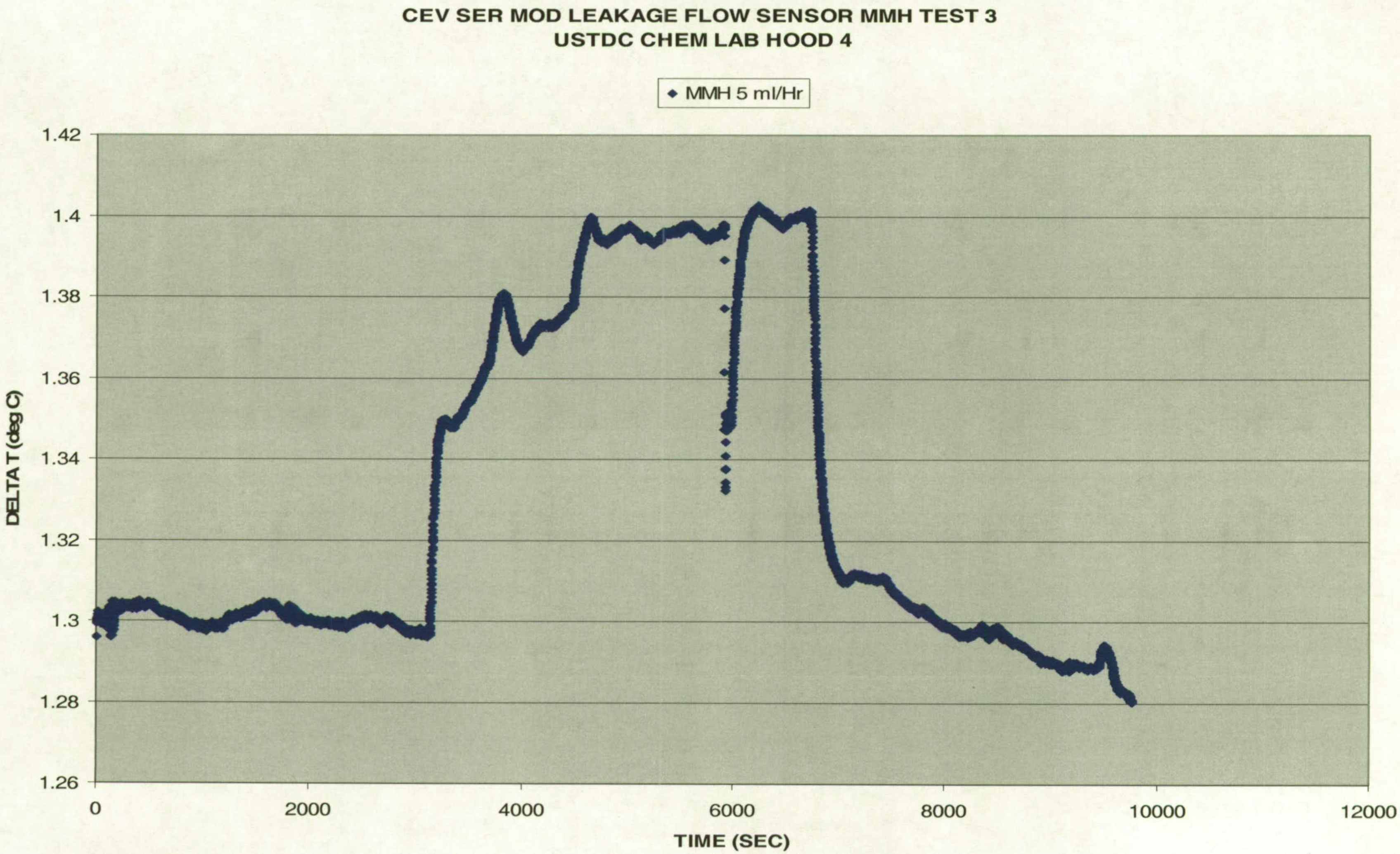
TEST SETUP IN HOOD 4
ACL 5/12/08



Water Flow 5 mL/hr



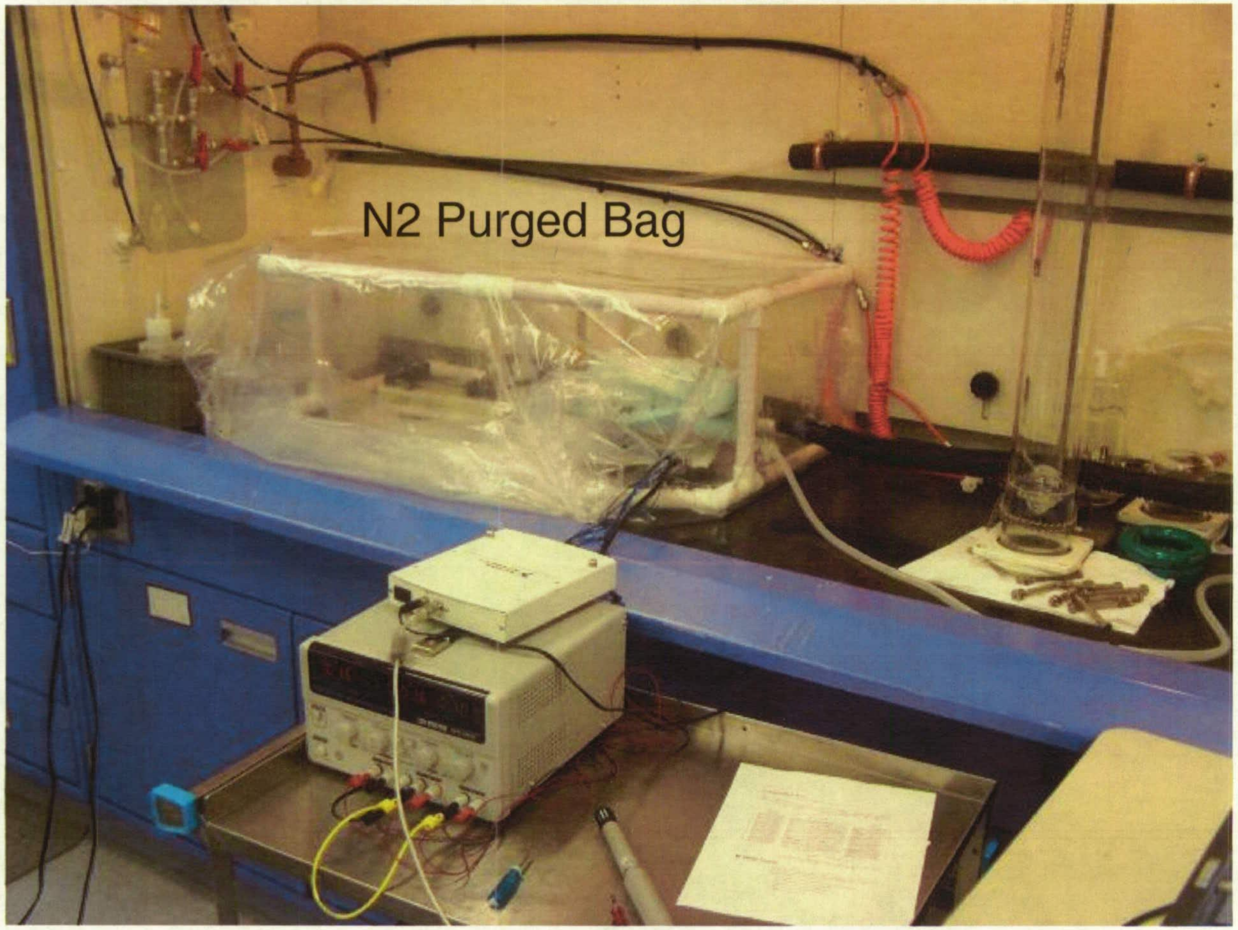
MMH Testing 5 mL/hr



MMH Results

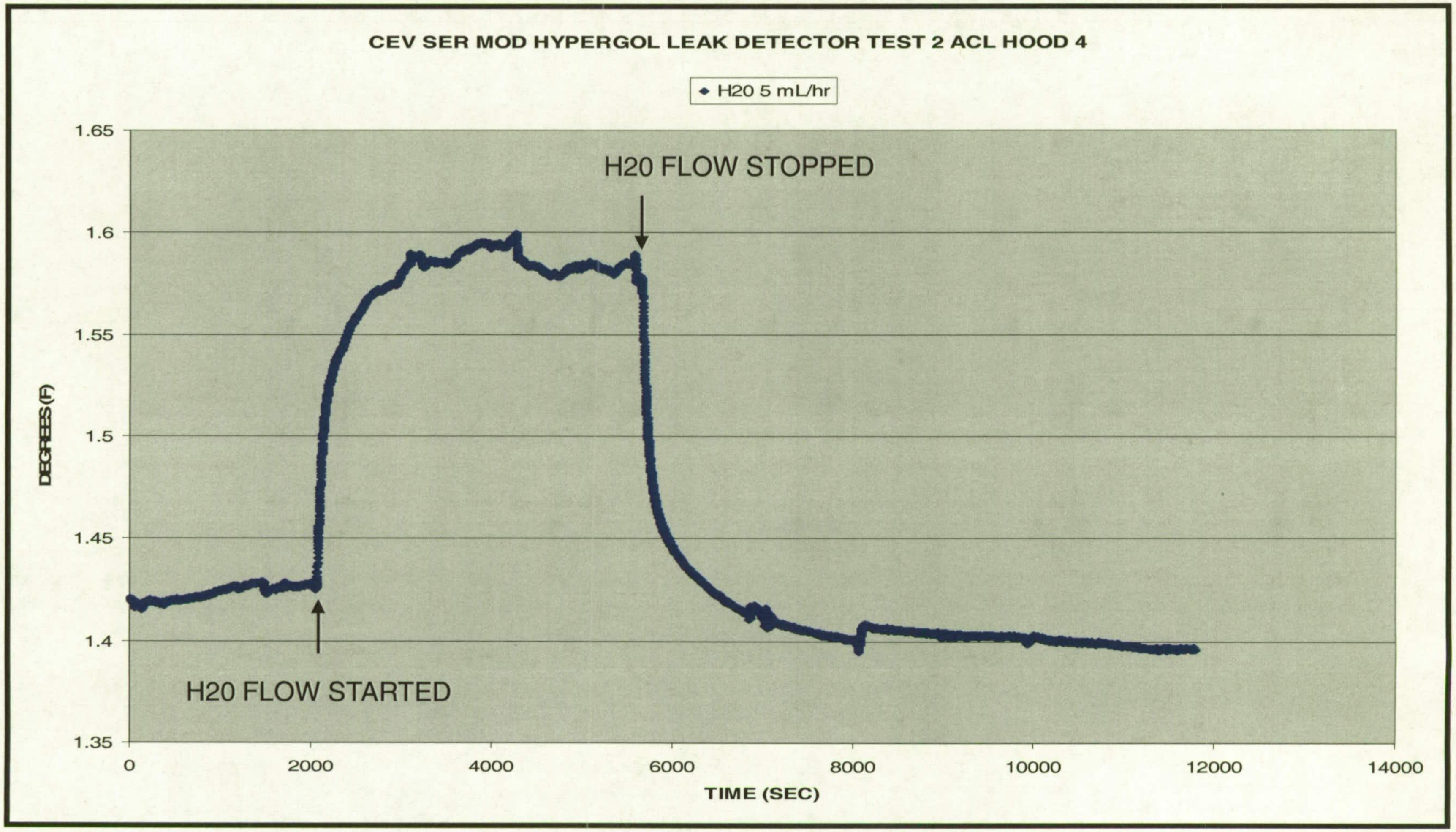
- Sensitivity: The delta T versus flow appears to be about 1/2 for MMH (0.1 C for MMH vs. 0.2 C for water).
- BUT: the flow was filled with bubbles due to MMH reaction with ambient air and with some of the components.
- A new set-up was designed with a N_2 bag and new materials (plus extensive reviews with WSTF).
- In addition, we found that the heat transfer adhesive that attached the sensors was deteriorating and had to evaluate and adopt new materials.
- Water flow testing has been successful (next pages) and MMH testing is scheduled for today (9/17/08).

New MMH Test Configuration



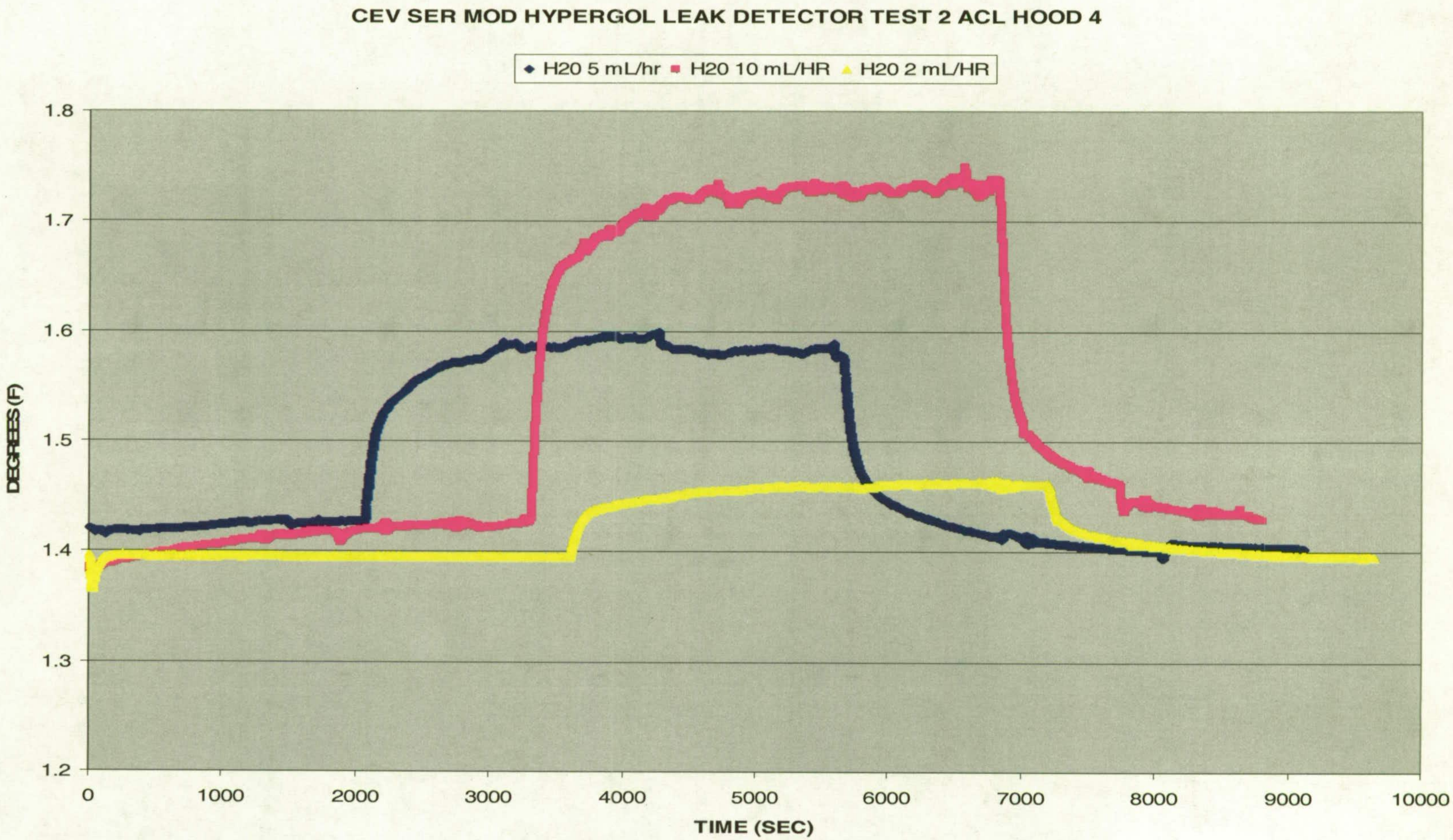
Water Flow Test Example

Data from 9/11/08



Summary of Water Flow Runs

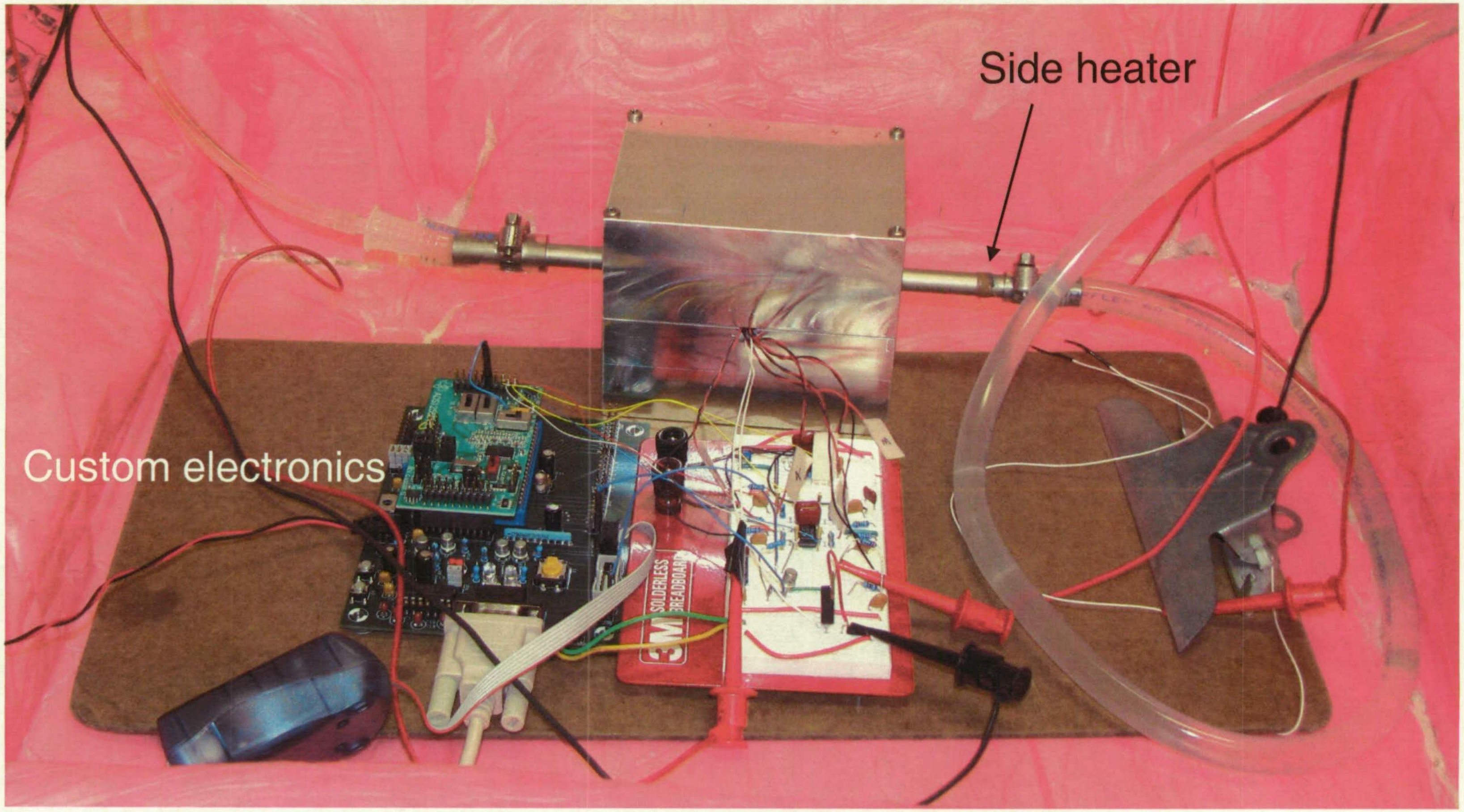
Data From 9/11/08



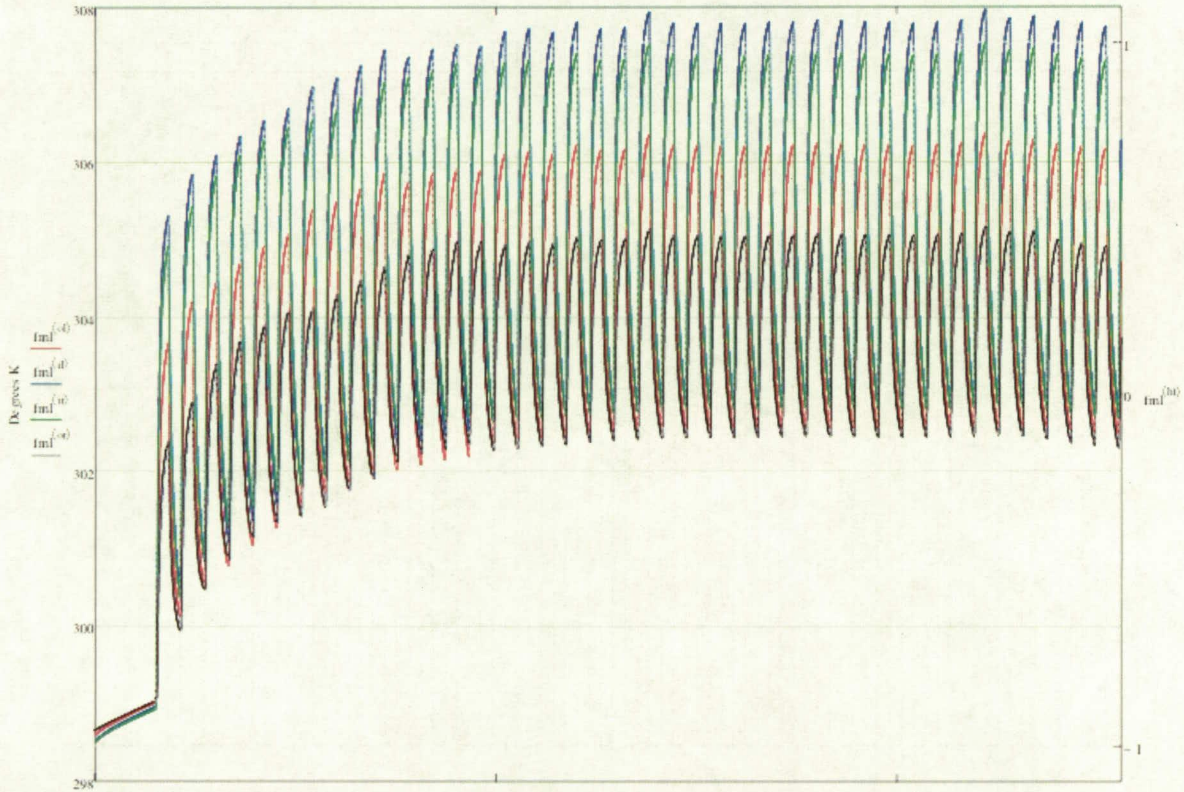
Second Gen Prototype Low Flow

- We recognized fairly early that one issue with the First Prototype is temperature gradients along the tube. These could be induced by engine firings if the sensor were located close to the RCS motor or by uneven solar heating of the CEV, and other environments.
- To address this issue, a new prototype was fabricated with four temperature sensors (an inner pair and an outer pair) and an Al case that would provide a "thermal short."
- After extensive bench testing with water along with data analysis, we decided that we would be better off operating in a pulse mode and taking double differences. In other words, turn on the heater for say 15 minutes and take the differences between the temperature sensors from the start of turn on to the turn off then difference between the inner sensors.
- We are also evaluating a curve fit approach using all four sensors.

Image of 2nd Prototype Sensor



Modulated Operation



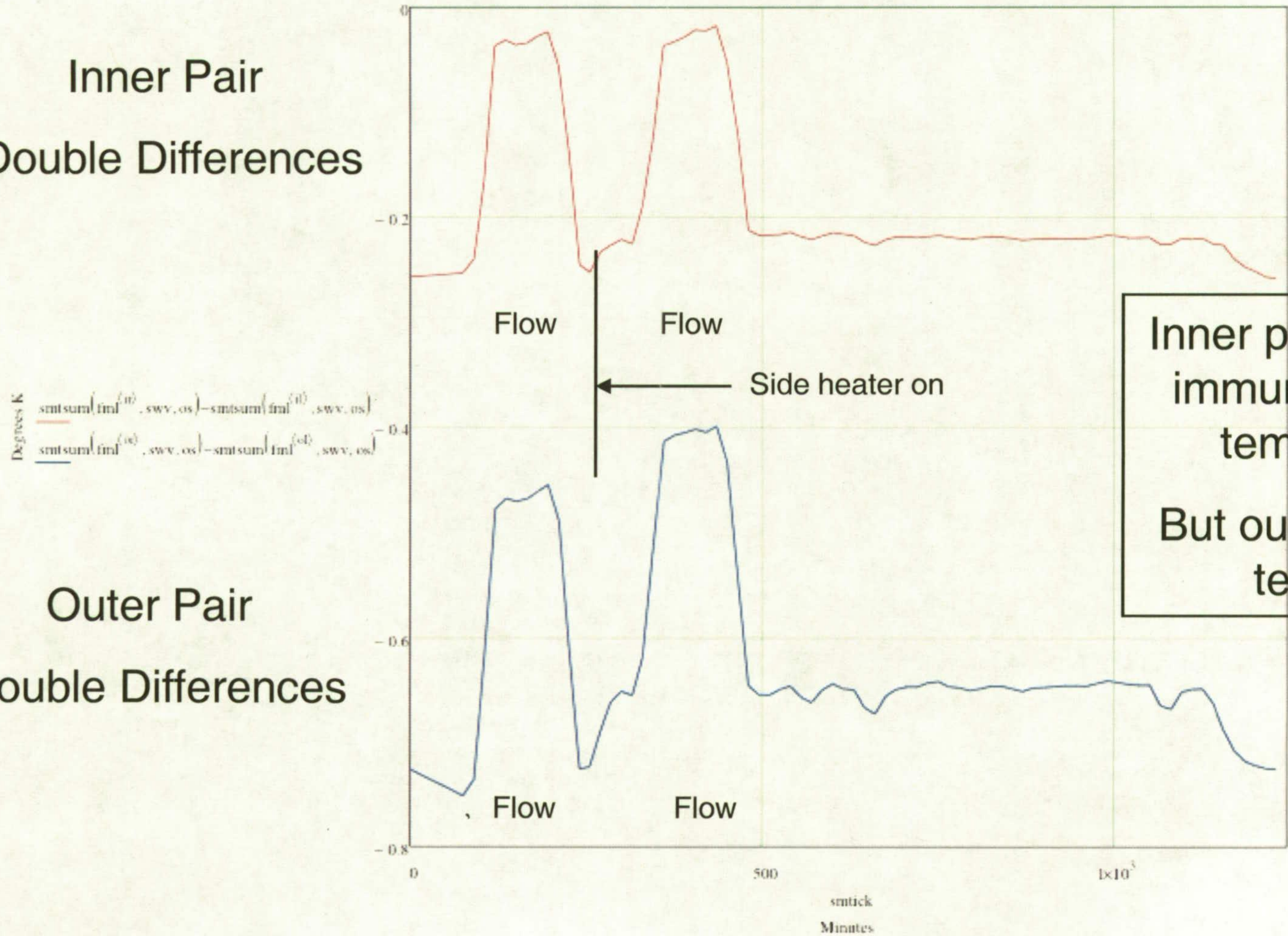
Plot shows the sensor modulated 15 min. ON, 15 minutes OFF over several hours. Two upper plots are the inner pair. During operation, water flow turned on twice, with and without side heater.

Double Difference Algorithm

Same data as previous slide

Inner Pair

Double Differences



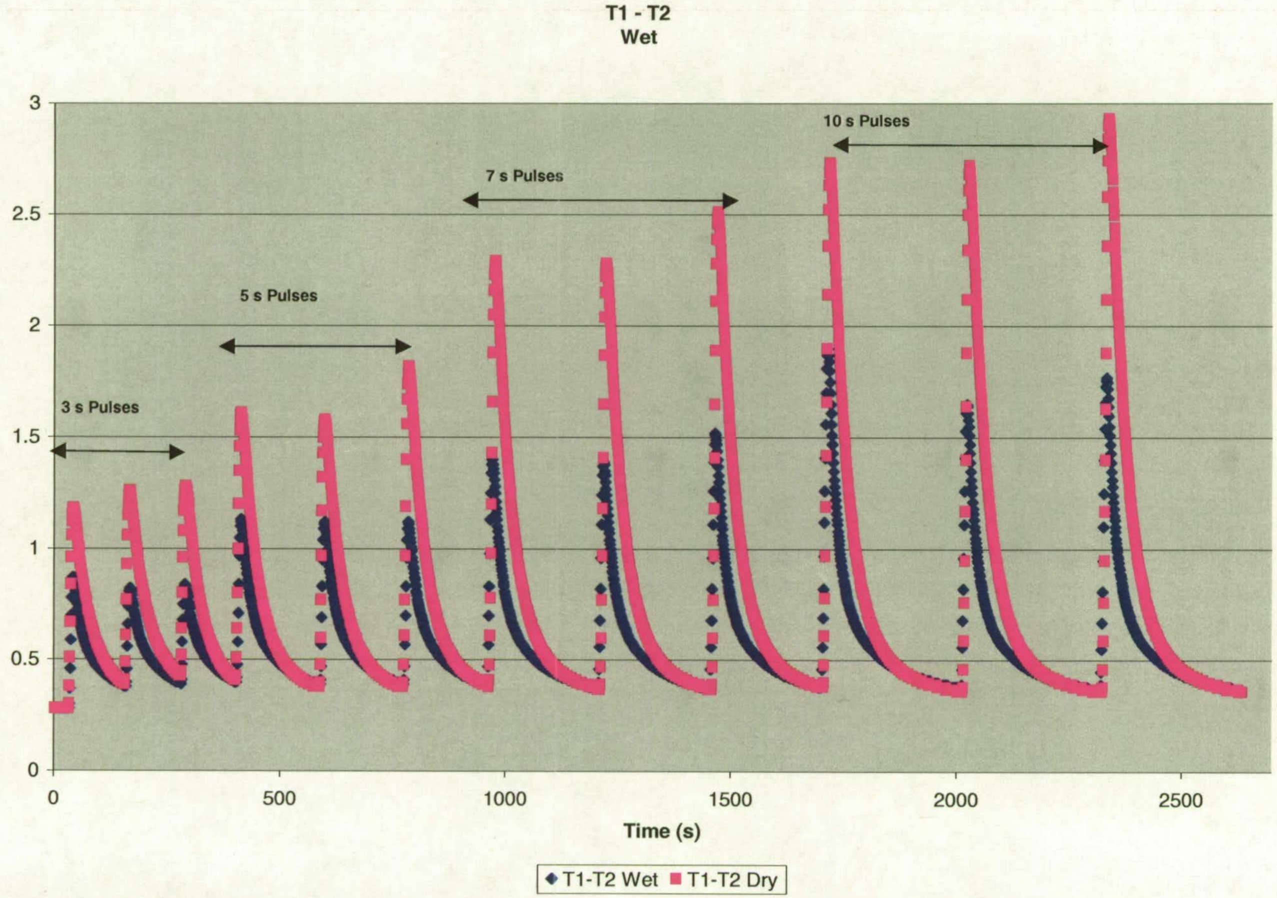
Outer Pair

Double Differences

Inner pair DD approx. immune to external temp. gradient

But outer pair shows temp. shift.

Wetness Testing



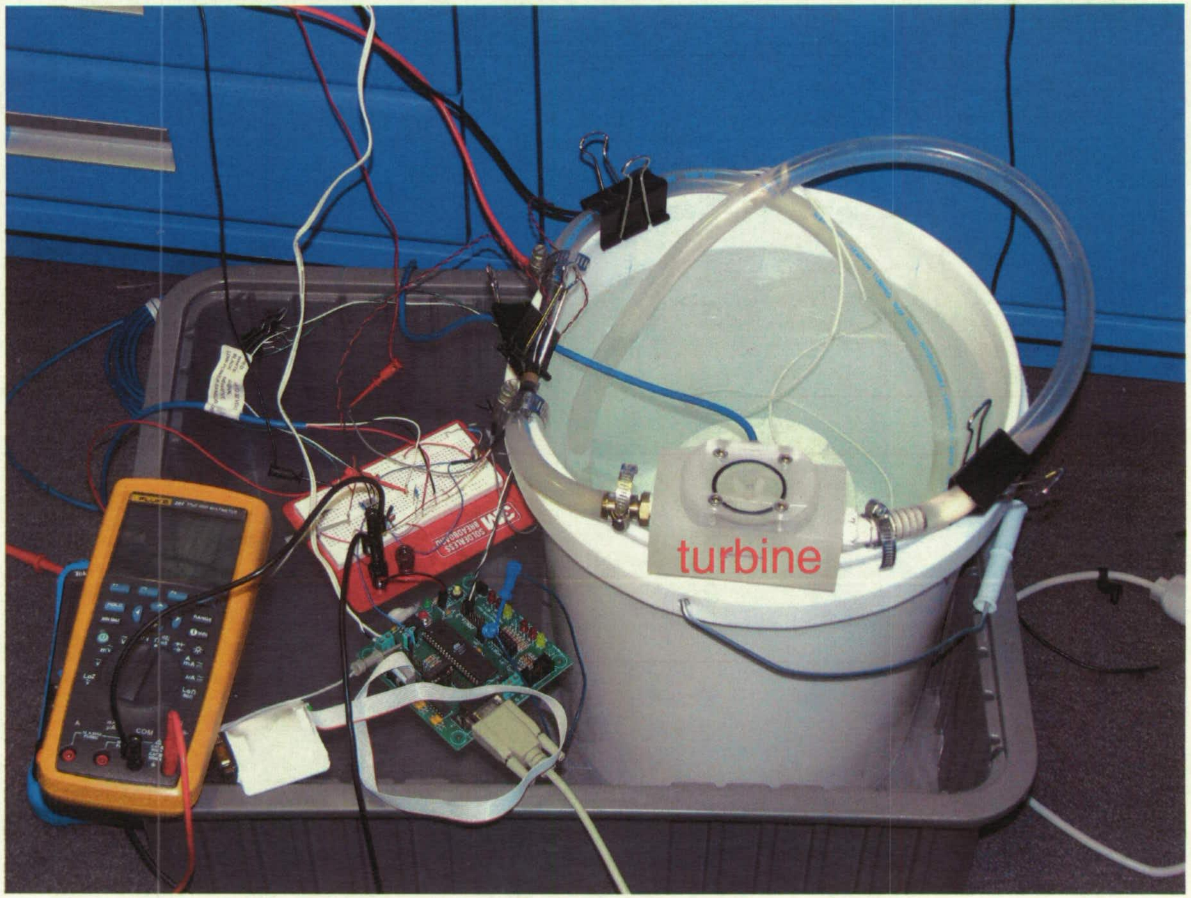
Short pulses of heating give about twice the temperature rise when tube is dry. We consider this concept demonstrated.

High Flow Testing

- The high flow concept is to have a heater and single temperature sensor, plus a closed loop control system to maintain the temperature constant.
- First test runs using sensor mounted to the top of the heater showed rapid control loop saturation.
- We are now repositioning the temperature sensor from on top of the heater to adjacent to the heater directly on the tube..

High Flow Test Bed

Test bed uses submersible fountain pump in bucket with in-line turbine flow meter.
Photo taken during attachment of new temperature sensor (under black clamp).



Next Steps

- Low flow testing with MMH is scheduled for today (9/17/08).
- Continue refining data algorithm to determine the best modulated heating approach to reliably detect >5 mL/hr and the need for additional temperature sensors.
- High flow meter is being modified for further flow testing.
- We consider wetness testing complete.
- Discuss FY09 goals.